ON A RAY METHOD FOR STUDYING DIFFRACTION OF WAVES EMITTED BY A PLANAR TRANSDUCER WITHIN A SOLID CONICAL-SHAPED MEDIUM

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INTRODUCTION

Increasing rocket engine performance is closely linked to as best a knowledge of the propellant combustion evolution as possible. Another important point is to estimate the protection material quantity to place between the combustion chamber and the propeller structure. After many methods such as « Strand Burner [1]», ONERA chose ultrasonic techniques whose most interesting feature is their non-intrusivity [2].

This work, then, is part of a study concerning thermal material ablation measurement (or propellant combustion speed) [3], [4].

STUDY FRAMEWORK

Ultrasonic sensors are situated radially on the outside wall of a combustion chamber. A conical-shaped medium is placed inbetween the propellant block and the sensor, its purpose being to protect the sensor from excess heat and pressure (figure 1). An ultrasonic wave emitted by the sensor is altered as it goes through the medium to its final destination (the transducer). These alterations are due to the nature of the medium being gone through as well as its intrinsic geometry.

This is why our purpose is the study of propagation of a pulse within an elastic conical-shaped medium : the problem is to determine the transducer impulse response within this tapered medium.

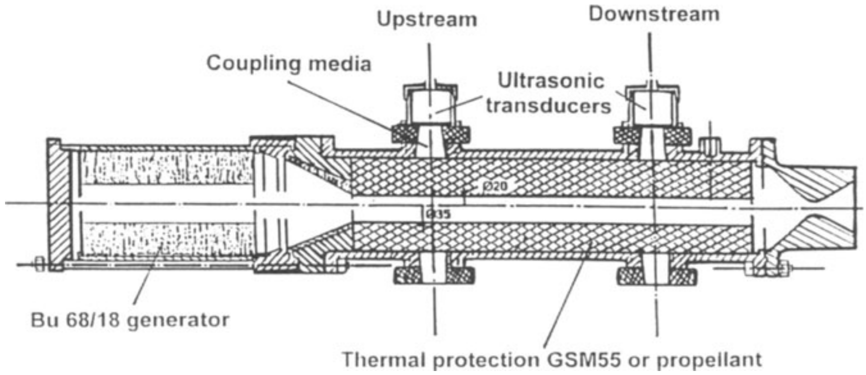

Figure 1. Overall view of a propeller used by ONERA with the transducers and the conical-shaped coupling medium.

RAY MODEL CHOICE

The complexity arising from a completely analytical study suggests the use of a geometrical model accounting for the characteristic dimensions of the different media as well as the working frequencies. The tapered shaped medium length is 0.07 m, the upper diameter is 0.032 m and the semi-aperture angle takes many values (0, 4, 8 degrees). The frequencies of the signal emitted by the transducer (diameter 0.0254 m) are 1 and 2,25 Mhz.

The ray model presented here consists in modelling of emitting disk as a collection of point-like sources [5]. Each emitting point generates a spherical wave on a radius of the disk; the space is swept along a direction given in spherical coordinates. Here is described what is called ‘ first mode ’ which is a direct mode of propagation (only one reflexion on the base of the tapered shaped medium before coming back to the transducer). A second mode is also considered and represented by one reflexion on the base and another one on the envelope : when the ray hits the base, one doesn’t take into account mode conversion with generation of transverse waves which give other longitudinal ones as they hit the envelope (figure 2). Considering T waves might be the object of future work. The study is restricted here to two modes of propagation : it is useless to consider higher modes since the increasing length of the rays induces amplitude diminution.

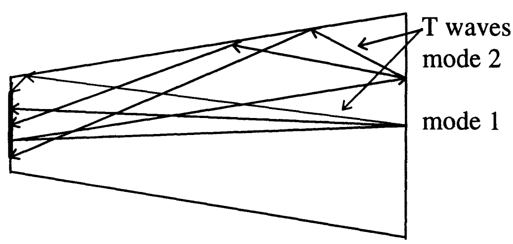

Figure 2. Conical-shaped medium with direct and indirect modes (first and second mode).

INTEGRATION PROBLEM

A crucial problem here is to establish a method with which to integrate the signal received on the transducer. Indeed, the relations between spacial and temporal variables are not as simple as in the case of reflexion on a planar interface [6] : the major difficulty arises from the curved shape of the interface represented by the envelope. On figures 3 and 4 are shown isochronous lines shapes for various emitter positions. One notices cusps and caustics, the discontinuous nature of which makes for difficult integration; in addition this method would be too long in calculation time. For these many reasons, one chose a classical method that consists in sweeping space with a constant solid angle : the sequence of discrete spots can then be considered approximately as making up a continuous line, these spots being created by rays -which are actually ray tubes- hitting the receiver. For each spot, the travel time 'it' is calculated; impulse response amplitude 'h' is increasing for the considered time 'it' according to formula : h(it)=h(it)+S/(C . it . Dt). Here, 'C' is the medium velocity, 'Dt' the time step and 'S' the surface intersected by ray tube on the transducer, for reception. This formulation is however valid under two main conditions :

1_the signal wavelength must be small enough compared to the conical envelope curvature : wave can therefore be considered plane and ray tube not disturbed by the interface,

2_the sweeping discretization must be fine enough, this is to avoid too great a phase rotation between ray tubes.

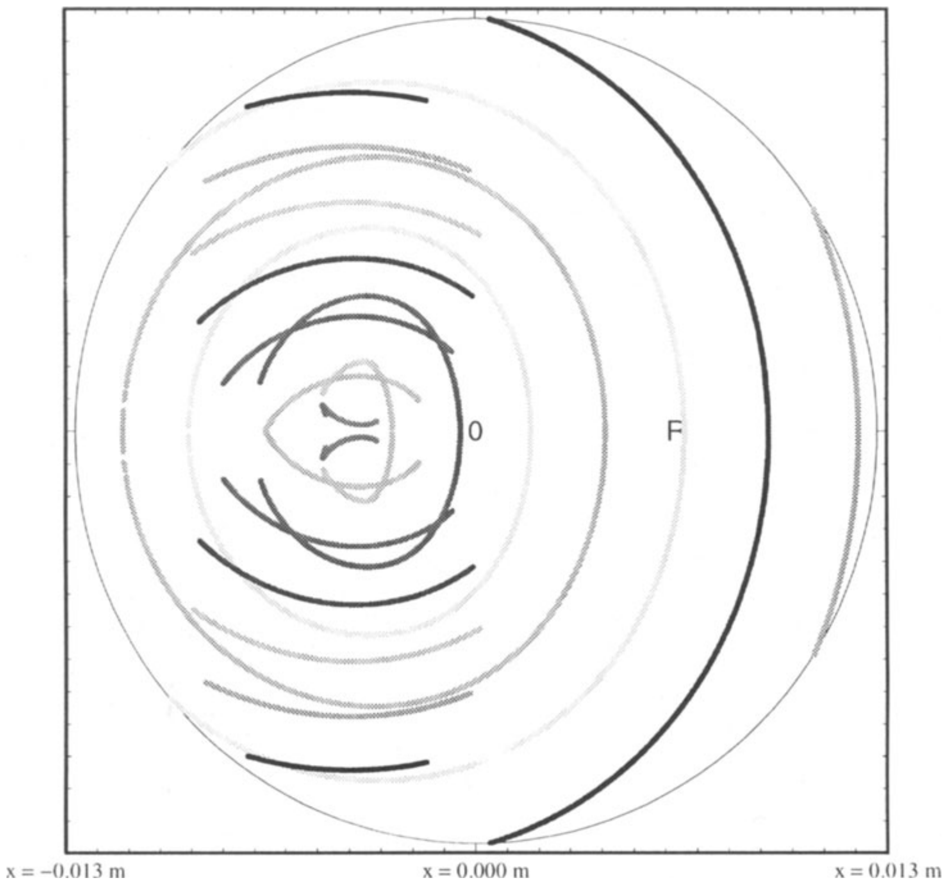

Figure 3. Isochronous lines for a receiver position situated at 0.5 Rt (Rt is the transducer radius). Half-aperture angle of cone is 4 degrees.

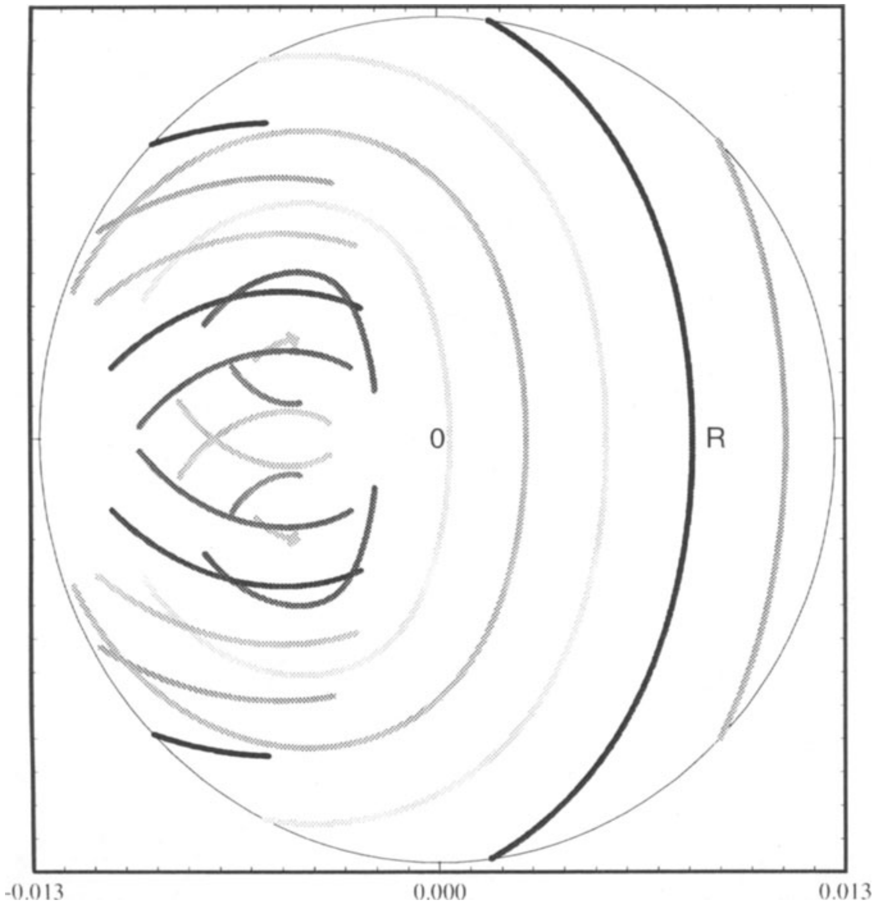

Figure 4. Isochronous lines for a receiver position situated at 0.7 Rt (Rt is the transducer radius). Half-aperture angle of cone is 4 degrees.

NUMERICAL RESULTS (I)

Impulse responses for various half aperture angles are shown on graphs of the figure 5. The medium properties chosen are as given further on. The increase of indirect part of the signal is particularly significant for higher angles. It is noticeable that these graphs give us an information on the amplitude which is only relative. The information on these impulse responses becomes of greater interest when the convolution is done with an arbitrary shaped signal. First, a sinusoidal function is convolved. The increasing part of the signal corresponding to the second mode is clearly highlighted on graphs of the figure 6. However, one has to take care about this convolution : the indirect part of the impulse response causes a great disturbance when the convolution is made with a sine but this influence may be less important with another signal type, as it will be seen in the next part.

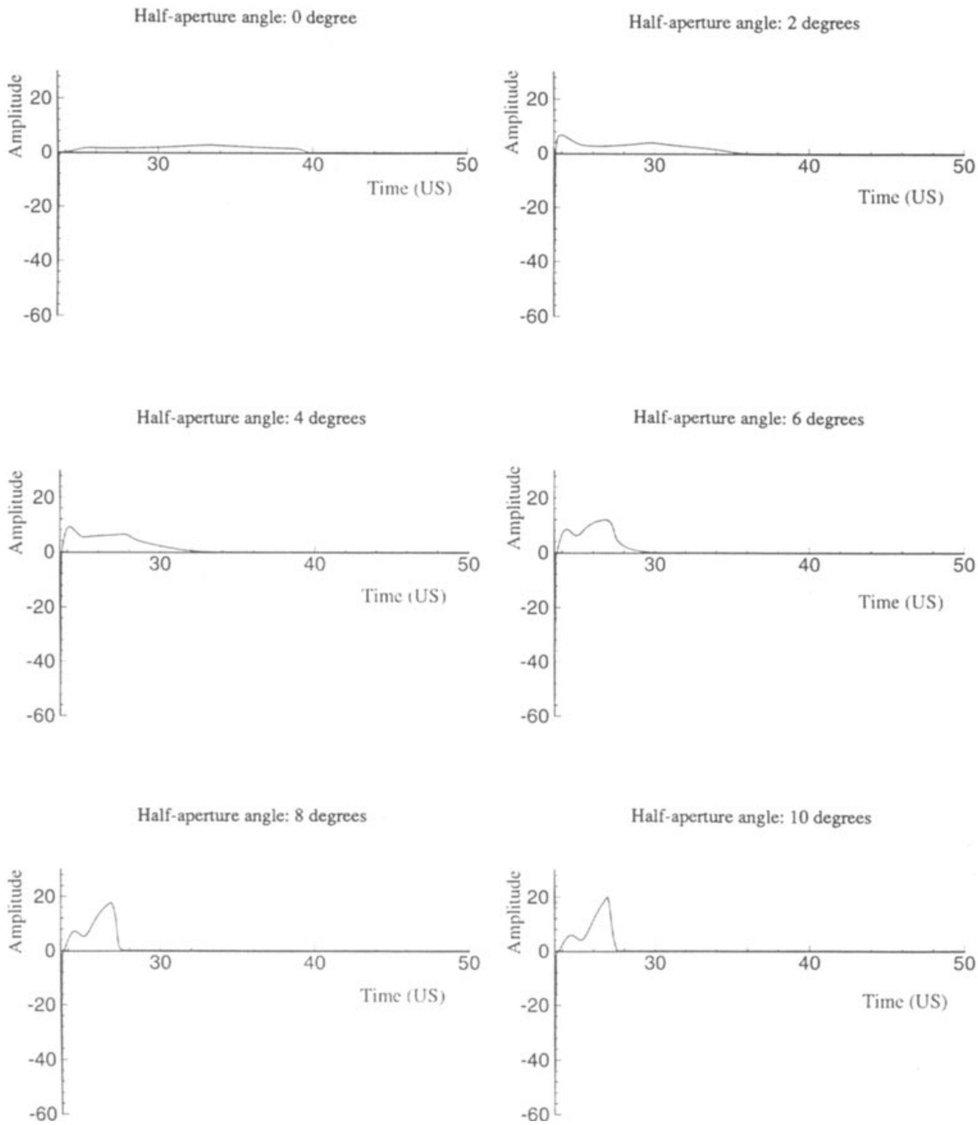

Figure 5. Impulse responses for various half-aperture angles (0, 2, 4, 6, 8 and 10 degrees).

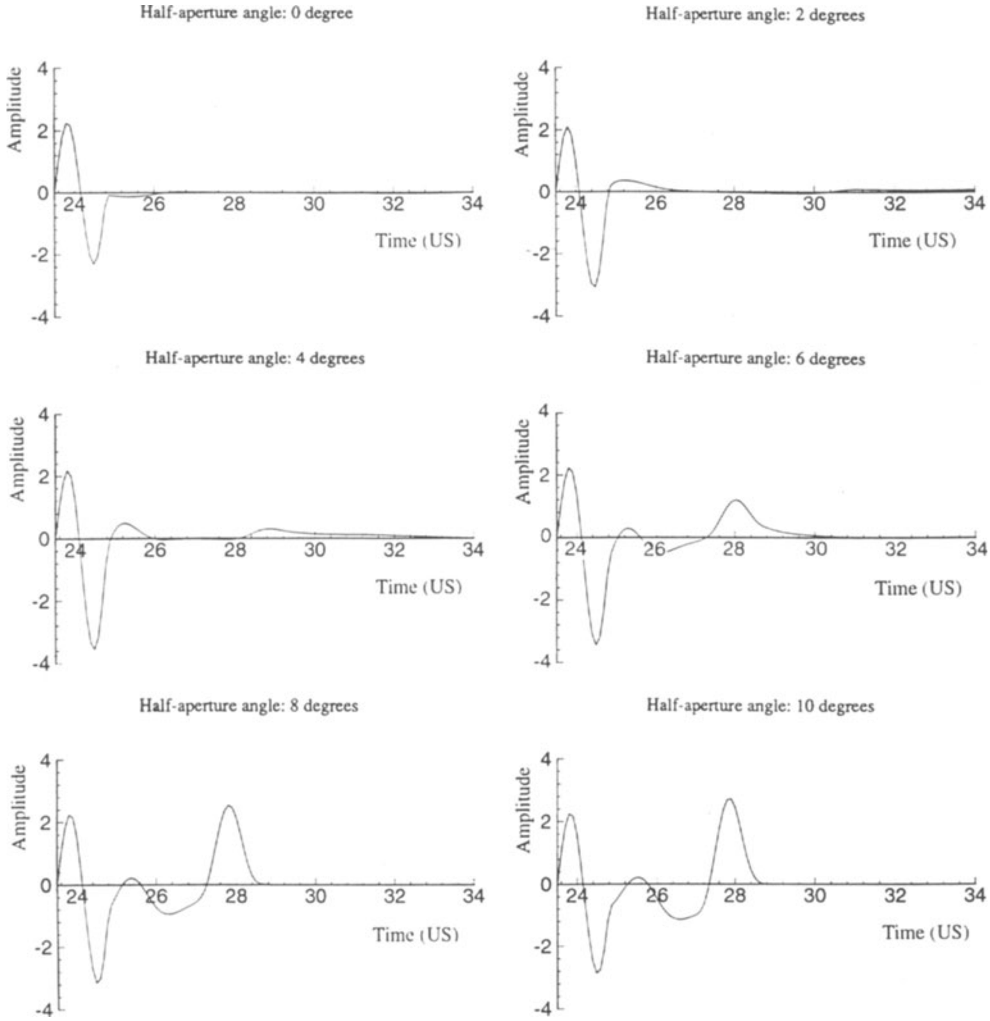

Figure 6. Convolution with a sinusoidal function for various half-aperture angles (0, 2, 4, 6, 8 and 10 degrees).

NUMERICAL RESULTS (II)

In the last part of this work, numerical results are confronted with experimental ones : the signal produced by a Panametric transducer at 1 Mhz is discretized : for this, a 0.0254 m diameter transducer is put on a cylinder bloc of silica with large diameter (velocity 5900 m/s, density 2203 Kg/m3). The obtained signal is discretized and injected into the code. Then one studies the wave alteration during its travel within a cylinder-cone bloc of silica (figure 7). This medium is chosen for its good elastic properties and minimal absorption. The transducer is placed on the top of the block. A direct comparison can be made on graph 8 between the input signal, the experimental and the numerical ones. The most significant information that can be obtained from the experimental signal is the alteration undergone by its tail end (between 2.5 and 7 microseconds). The amplitude of the signal in this zone is decreasing and passes under zero value until 5.5 microseconds; after this time value, a small alternance is noticeable. These phenomena can be observed on the numerical signal, but are amplified.

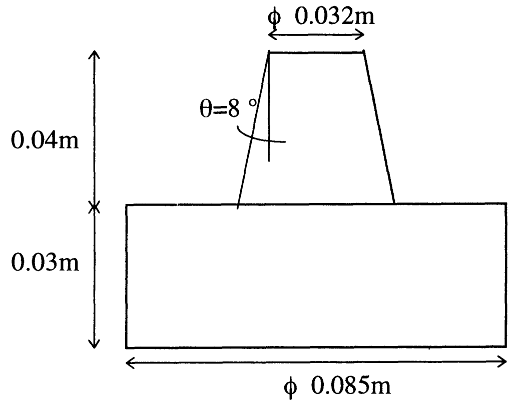

Figure 7. The cylinder-cone bloc of silica with its dimensions.

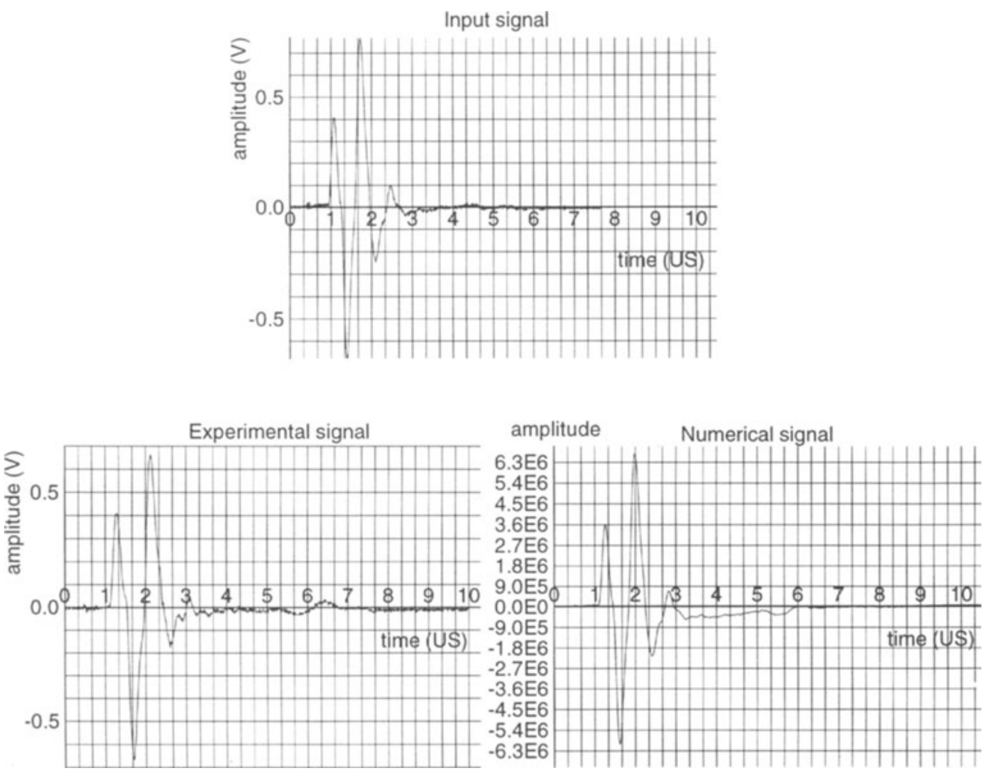

Figure 8. Comparison between the input signal, the experimental and the numerical ones.

COMMENTS AND PERSPECTIVES

Confrontation between numerical results and experimental ones seem to confirm our choice of a ray model with its necessary approximations. This geometrical approach offers many advantages :

_the calculation time is quite short (about 20 minutes on a common Silicon station),

_modifying configuration, dimensions and frequencies is easy,

_introducing particular interface conditions as well as absorption factor may be done,

_accounting for mode conversion seems possible without great difficulties,

_the configuration shown on figure 7 allows us to consider using a more general one, such as successive sheets; their thicknesses have to be adjusted with the frequencies of the signal injected into the code. This would permit the study of wave propagation in a multi layers medium, each one affected by particular characteristics (density, celerity, absorption...) : thermal gradient introduction by constant temperature layers may be envisaged too.

ACKNOWLEDGEMENTS

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